Use of Radar Profilers in Multi-Sensor Ground Validation for TRMM and GPM

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***Abstract*— Realistic simulation of the hydrologic cycle in global climate models remains a difficult challenge since climate models cannot resolve convective systems. Only satellites can provide global precipitation estimates needed to validate global climate models. The algorithms used to relate precipitation estimates to satellite observables require ground-based observations for development and validation purposes. In this paper we outline how profilers can be used in combination with other ground-based instruments to support the retrieval of precipitation estimates from satellites. The profilers provide quantitative information on the vertical structure and temporal variability of reflectivity and precipitation parameters related to drop-size distributions (DSD) that are essential for quantitative precipitation estimation. The profilers are most naturally calibrated by reference to a collocated disdrometer and are in turn useful for providing calibration for scanning radars. The use of profilers for ground validation is illustrated by examples drawn from the Tropical Rainfall Measuring Mission (TRMM) Ground Validation field campaigns and the Global Precipitation (GPM) Front Range Pilot Project conducted in Colorado in 2004.**

Keywords-precipitation; profiler; TRMM; GPM; Ground Validation.

I. INTRODUCTION

Much of the energy that drives the general circulation that determines global weather and climate comes from the release of latent heat in precipitating cloud systems [1, 2]. Because of the vast difference in scales between convective clouds and the large-scale circulation, it is impossible to treat convection and precipitation processes explicitly in global climate models [3]. Since the hydrologic cycle and precipitation are difficult for models to simulate, it is of critical importance to have reliable estimates of global precipitation in order to develop and validate models capable of realistically simulating the hydrologic cycle. Recent efforts have also been made to assimilate precipitation data into numerical models in order to achieve more realistic simulations [4, 5].

While satellite imagery has provided valuable information on the organization of convective systems in the tropics, quantitative estimates of precipitation have relied upon the development of sophisticated algorithms designed to retrieve precipitation amount from passive satellite-borne radiometers and active satellite-borne radar as utilized in TRMM.

The rationale for TRMM is presented in [6]. The TRMM satellite contains both passive radiometers and an active Precipitation Radar [7] that have been used to cross validate the precipitation estimates retrieved from these instruments. In this paper we consider the role of ground-based instruments in providing calibration and validation for TRMM and future satellite precipitation missions. It is anticipated that for future satellite precipitation missions a suite of ground-based instruments will be needed to provide physical validation of the algorithms used to retrieve precipitation estimates from the satellite observables.

Precipitation profiling from ground-based radar profilers designed to look vertically has been demonstrated to be useful for ground validation of satellite precipitation estimates. The precipitation profilers are low-powered versions of the boundary layer radars developed at the NOAA Aeronomy Laboratory over a decade ago for wind measurement. Beginning with TOGA COARE and continuing with several TRMM and GPM-related field campaigns, profilers have been utilized to provide a highly-resolved continuous visual record of the evolution of precipitating cloud systems.

This paper summarizes recent progress in the use of ground-based radar profilers in multi-sensor field campaigns. The original plan for ground validation for the TRMM satellite presented in [8] did not utilize profilers. However, it has been found that empirical Z-R-type relationships are inadequate to provide the desired accuracy of rain retrievals needed to validate TRMM. Specifically, there is a recognized need to measure drop-size distributions in order to obtain a more direct measure of precipitation parameters. Here, we address the use of rain gauges, disdrometers, profilers and scanning radars to give vertically-resolved estimates of precipitation parameters over the domain covered by a conventional scanning radar.

II. PRECIPITATION PROFILING DURING TRMM GROUND VALIDATION FIELD CAMPAIGNS

For the TRMM field campaigns the NOAA Aeronomy Laboratory developed a pair of vertically-looking profilers in order to reveal the vertical structure of the precipitating cloud systems over the profilers. The observations yield the Doppler spectra of moving targets within the radar observing volume. The Doppler spectra are processed to yield vertically-resolved time histories of equivalent reflectivity, Doppler velocity and spectral width over the profilers.

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The 915 MHz profiler used for TRMM is similar to the 915 MHz profiler described in [9, 10] and the S-band profiler is a low-powered version of the 2835 MHz profiler described in [11]. The profilers are shown in Fig. 1 as they were deployed during TExas FLorida UNderflights (TEFLUN) B. In TEFLUN B the profilers were located east of Holipaw, FL on the south side of US 192 at the Triple N Ranch. This site is about 35 km west of the Melbourne WSR-88D and a similar distance northwest of the NCAR S-pol radar which had been deployed in central Florida in support of TEFLUN B.

For TRMM Ground Validation Field Campaigns the two profilers were equipped with collocated disdrometers and rain gauges to provide calibration for scanning radars which in turn were used to calibrate the TRMM precipitation estimates. For these field campaigns a Distromet RD-69 disdrometer also known as a Joss-Waldvogel disdrometer (JWD) was utilized to provide a calibration for the profiler reflectivity. For the TEFLUN campaign we integrated the data stream from the JWD into the AL profiler data stream in order to guarantee that the timing of the profiler and disdrometer measurements were coincident. A detailed account of the use of profilers in the TRMM Ground Validation Field Campaigns can be found in [12,13].

Figure 1. The Aeronomy Laboratory profiler pair located at Triple N Ranch in central Florida during TEFLUN B

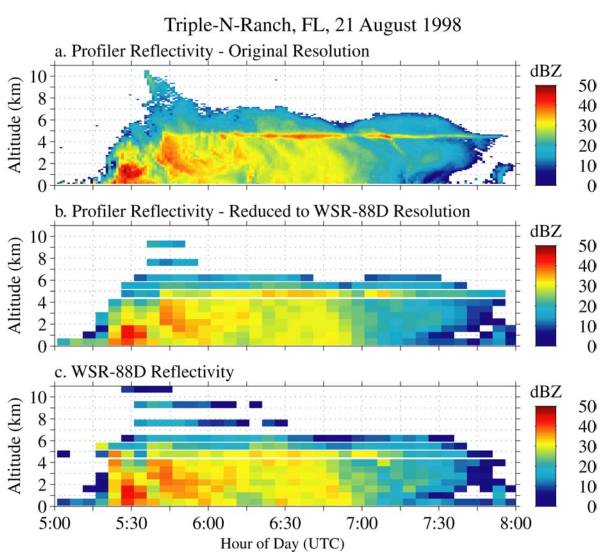

Figure 2. Comparison of Time height cross sections of reflectivities observed by profiler and Melbourne, FL WSR-88D scanning radar on 21 August 1998 in central Florida during TEFLUN B.

III. COMBINED USE OF PROFILERS WITH DISDROMETERS AND SCANNING RADARS

Results of the TRMM Ground Validation Field Campaigns and other field campaigns indicate that profilers used together with disdrometers and rain gauges provide an effective independent means for calibration and validation of scanning radar estimates of precipitation. Williams et al. [14,15] consider the combined use of these instruments to provide reference precipitation parameters with error characteristics to monitor and continuously validate precipitation estimates from the scanning radar. The domain of interest is on the order of the area of a circle of 50 km radius (i.e., the domain of a scanning radar limited by the range in which it retains good height resolution).

Used with disdrometers and rain gauges, profilers can provide an efficient means for tying ground-based observations from *in situ* sensors with the scanning radar observations above the surface since profiler observations cover a range of altitudes and have an observing volume intermediate between the relatively small observing volumes of rain gauges and disdrometers and the much larger observing volume of a scanning radar. This combination of instruments is likely to be a primary component of real-time observations supporting any future ground validation Supersite for GPM.

An example of the combined use of a profiler with a scanning radar is reproduced in Fig. 2 from TEFLUN B. Shown in Fig. 2 are the time-height cross sections of reflectivity observed by the profiler and the Melbourne, FL WSR-88D scanning radar over the profiler site. In the top panel the profiler data are reproduced with their native vertical resolution. In the middle panel the profiler reflectivities are degraded to coincide with the temporal and spatial sampling of the volume-scanning WSR-88D. In the bottom panel the WSR-88D reflectivities are shown. The close correspondence of the reflectivities in the middle and bottom panels demonstrates that the two sets of reflectivities can be intercompared quantitatively over the profiler. Furthermore, as shown in [14,15] the profiler observations provide an excellent high-resolution description of the evolution of the variability of the precipitation fields over the profiler within the time and spatial domain sampled by the scanning radar. In the next section we draw upon the GPM Front Range Pilot Study observations to illustrate the utility of combining these instruments in any ground validation effort.

IV. IV. USE OF PROFILERS IN THE GPM FRONT RANGE PILOT STUDY: A CASE STUDY

The GPM Front Range Pilot was conducted by researchers from Colorado State University, the NOAA Aeronomy Laboratory and the NOAA Environmental Technology Laboratory during the spring and summer of 2004. During the GPM Pilot the participating institutions gained experience utilizing scanning radars, disdrometers and rain gauges to

quantify precipitation over a domain that extended along the front range between Boulder and Greeley. The CHILL radar operated by CSU (at the Greeley Municipal Airport) and the ETL X-pol located in Erie were utilized to evaluate the capability of the X-pol scanning radar to provide quantitative precipitation estimates in light rain. At the same time, several profilers were utilized to gain experience on the retrieval of DSD parameters using profilers operating at different frequencies to optimize the retrieval of DSD by resolving Bragg and Rayleigh components of backscatter during precipitation. In this section we present some preliminary results for a precipitation event that occurred June 16-17. Only the profiler and disdrometer observations are reproduced here.

The precision of measurement from the disdrometer and profiler instruments is good enough that the disdrometer can be used for absolute calibration of the profiler [16]. The disdrometer also provides validation of the DSD parameters retrieved from the profiler. Fig. 3 reproduces time-height cross-sections of the precipitation event of 16–17 June 2004 as seen at the BAO by the 2835 MHz profiler. This event was unusual since it included a period of very light rain that was confined to the lowest 1-2 km above the surface followed by a sequence of convective showers that continued through the remainder of the day. Thus, a great variety of conditions are represented in this event. The profiler contribution is immediately evident in its ability to clearly show the vertical structure of the precipitating clouds and their evolution throughout the day. Time series of reflectivity from the JWD and the profiler at the second range gate centered at 316 m AGL are compared in Fig. 4.

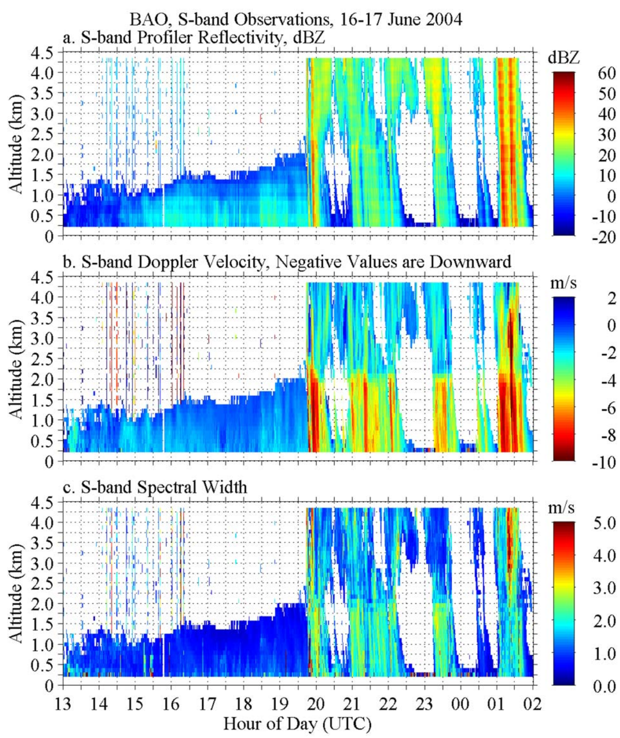

Figure 3. Time Height cross sections of reflectivity, Doppler velocity and spectral width observed on June 16-17 at the BAO in Erie, CO during the GPM pilot.

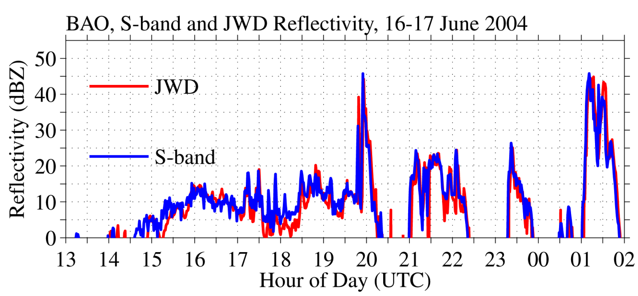

Figure 4. Comparison of profiler reflectivities with disdrometer reflectivities obtained on June 16-17 at the BAO in Erie, CO during the GPM pilot.

The GPM Front Range Pilot provided an opportunity to demonstrate the ability of the ground-based instruments to yield estimates of the DSD parameters within selected case studies. Below, we examine results from the 16-17 June case study.

There are several different forms of the drop-size distribution *N(D)* in common use. In recent years it is becoming more common for the DSD to be represented by a normalized gamma function because the 3 parameters describing the DSD are independent. One normalization is given in [17] expressed as

$$N(D) = N_w \frac{6}{4^4} \frac{(4+\mu)^{\mu+4}}{\Gamma(\mu+4)} \left(\frac{D}{D_m}\right)^{\mu} \exp\left[-(4+\mu)\frac{D}{D_m}\right] \quad (1)$$

where D_m is the mass-weighted mean drop diameter, μ is the shape parameter of the drop size spectrum, and N_w is the normalized drop concentration so that the liquid water content remains constant even if μ changes. N_w is expressed using

$$N_w = \frac{4^4}{\pi \rho_w} \left(\frac{10^3 W}{D_w^4}\right) \quad (2)$$

Where ρ_w is the density of water and W is the liquid water content.

While N_w and D_m represent the amplitude scaling and the mean drop size of the DSD, the width of the DSD in the liquid water content domain is estimated using

$$\sigma_m^2 = \frac{\int N_w (D-D_m)^2 D^{3+\mu} \exp\left(-\frac{4+\mu}{D_m} D\right) dD}{\int N_w D^{3+\mu} \exp\left(-\frac{4+\mu}{D_m} D\right) dD} \quad (3)$$

The 16-17 June case provides an excellent opportunity to compare DSD parameters using the JWD and the 2835 MHz profiler. Fig. 5 shows time series of N_w, D_m and σ_m retrieved from the second range gate of the S-band profiler centered 316 meters above the ground at the BAO in comparison with the values obtained from the JWD at the surface. While more work will be needed to completely define the error characteristics of these estimates, the agreement of these preliminary estimates is encouraging.

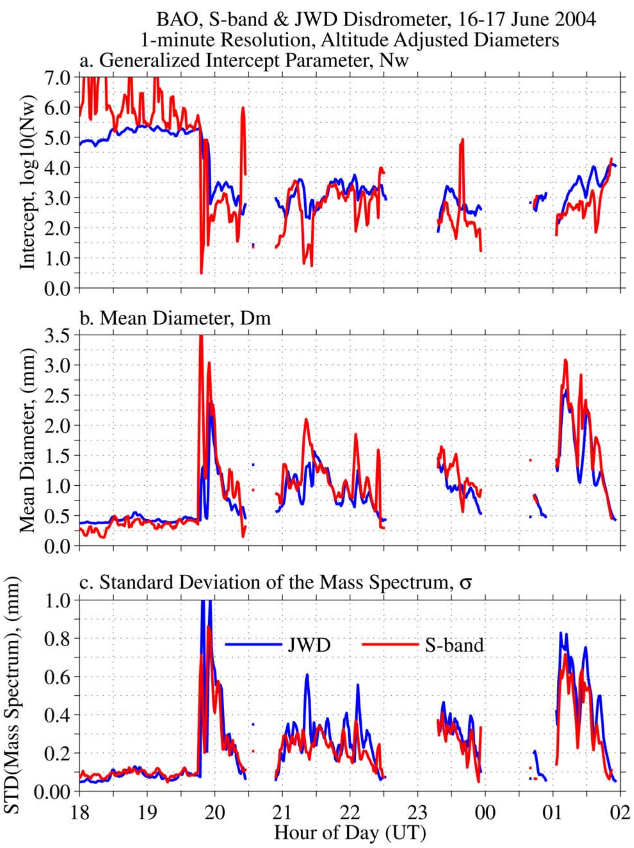

Figure 5. Comparison of DSD parameters retrieved from profiler observations with DSD parameters retrieved from JWD disdrometer at Erie, CO.

V. Concluding Remarks

Profiler observations have been successfully utilized in TRMM Ground Validation Field campaigns along with disdrometers, rain gauges and scanning radars to provide ground truth for estimates of precipitation retrieved from TRMM. In future GPM ground validation efforts it is anticipated that the emphasis on ground validation will shift away from rain mapping at the surface to collecting the data needed to validate the algorithms used in the retrieval of precipitation from satellite observations. While the ground validation efforts will likely be focused on two sites (one oceanic and one continental site), there is a recognized need to provide ground validation for a diverse set of precipitation climatologies which may not be present at the primary validation sites. Profilers can play an important role in ground validation at the primary sites and provide a cost effective validation tool for use at secondary sites.

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